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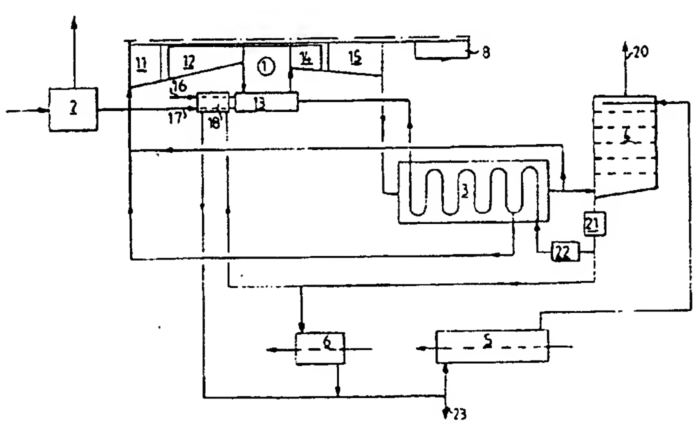

(57) Abstract

Method for power generation through combustion of gaseous fuels in a thermal power generation cycle with a gas turbine as principal machine. Working medium in the gas turbine is the mixture of water vapor and carbon dioxide produced through combustion of the fuel gas with oxygen in the gas turbine's combustor, said combustor being supplied with, partly the flow of steam produced in a steam generator connected to the turbine's exhaust outlet and partly a part flow of the flue gas from said steam generator after compression under direct or indirect cooling in the gas turbine's compressor. The balance of flue gas from the steam generator is utilized for production of hot-water in a scrubber, said hot-water being utilized, partly as feed water to the steam generator, partly as cooling medium for direct cooling through atomization in the recirculated part flow of flue gas from the steam generator, partly for preheating of fuel gas and oxygen. The method, which can utilize all gaseous fuels, gives for instance with natural gas a high total efficiency power/fuel (55 %), whereby the only by-products are moist carbon dioxide with a low content of oxygen and water vapour useful for production of liquid carbon dioxide and hot-water, for instance useful for selective heating purposes.

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METHOD AND PLANT FOR POWER GENERATION IN A GAS TURBINE BASED ON GASEOUS FUELS IN A CYCLE WITH THE RESIDUAL PRODUCTS CARBON DIOXIDE AND WATER, RESPECTIVELY

Power generation based on gaseous fuels in a combined cycle with gas as well as steam turbines has become an appreciated method for power generation, above all because of the relative simplicity and high efficiency of the method. The only real disadvantage of the method is the unavoidable carbon dioxide emission, a disadvantage the method shares, in lower degree however, with all other methods based on fossil fuels and which all impair the carbon dioxide balance of the atmosphere and cause the so called green house effect.

Several methods to eliminate the carbon dioxide emission from power generation based on fossil fuels have been published. Among these methods specially two have been much discussed: Increase of forest area and absorption of carbon dioxide from the flue gases followed by dumping, respectively.

Increase of forest areas implies change of an area´s type of vegetation by planting of species with larger ability of carbon dioxide capturing. Tropical forests have proved to be specially effective for this purpose. Thus, power generation and carbon dioxide capturing are not locally tied up to each other in this case. The cost for carbon dioxide capturing with this method has been estimated to between 10% (u-countries) and 50% (i-countries) of the cost of primary nuclear power.

Carbon dioxide absorption implies that the flue gases from the combined cycle are scrubbed with a water solution holding substances like ethanol amine, which binds carbon dioxide. By heating the solution the carbon dioxide is stripped off and can through compression and cooling be condensed to a liquor, which can be dumped (as chlathrate) in the depth of the oceans, in exhausted oil and gas wells, aquviferes etc. The cost for carbon dioxide capturing by this method are high and have been estimated to increase the kWhe cost of a combined power station by about 60%.

The present invention implies a method of power generation based on gaseous fuels with a higher efficiency than that, which can be reached in a conventional combined cycle and which further has the advantage of nitrogen free emissions of moist carbon dioxide and water, respectively, enabling dumping as above. The method implies a thermal power generating cycle with a gas turbine as the principal machine, whereby the working medium of the gas turbine is the gas mixture of steam and carbon dioxide, which is formed by combustion in the gas turbine´s combuster of fuel gas with oxygen in a somewhat over-stoichiometric flow in relation to the flow of the fuel gas, and with a simultaneous flow to the combuster of the steam, which is produced with adapted pressure in a steam generator connected to the exhaust gas outlet of the gas turbine and with a simultaneous recirculation to said combuster of a part flow of the flue gas from said steam generator after compression in the gas turbine compressor, temperature controlled by direct or indirect cooling, whereby the feed of fuel gas to said combuster is controlled in such a way that produced hot gas mixture has a inlet temperature adapted to the gas turbine.

According to the invention the non-recirculated part of the flue gas flow from the steam generator, containing carbon dioxide and to the larger part water vapour, is utilized for production of hot-water in a scrubber of known type. The hot-water is utilized, partly as feed water to the steam generator, partly for direct cooling in the compressor of recirculated part flow of the flue gas from the steam generator through moistening of the part flow beyond the saturation limit with atomized hot-water before the compression. Indirect cooling is possible in a twin-speed compressor but implies considerable interference on today´s gas turbine construction.

The flue gas from said scrubber (moist carbon dioxide) can with known methods be converted to liquid carbon dioxide, which can be dumped as above. The cost for carbon dioxide capturing in connection with the invention will be very low and is together with the cost for the dumping more than out-

balanced by the benefit from the higher thermal efficiency, which the method according to the invention brings about. The method enables thus a cost effective power generation based on gaseous fuels, natural or produced by oxygen gasification of carbonaceous fuels such as fossil fuels. Power generation according to the method of the invention does not affect the biosphere negatively and is equally environment friendly and besides more energy effective than power generation based on a conventional combined cycle and biofuels.

In order to further elucidate the invention it is described more in detail with reference to fig. 1, which shows an elementary flow diagram of an embodiment of the invention based on natural gas and a commercial aero-derived gas turbine with shaft in one piece (GE/LM 6000) and with reference to fig. 2, a variant of the method shown in fig. 1, showing the method based on a gas turbine of industrial type.

The method according to fig. 1 works in the following way:

Natural gas (16), preheated (18) with hot water from the hot-water scrubber (4), is fed with a controlled flow to the combuster (13) of the gas turbine (1) wherein to the gas turbine adapted pressure (30 bar) is maintained. Oxygen (17) (O_2 concentration > 85%, preferably > 92%), produced in a separate conventional unit (2) through distillation of liquid air and preheated in the same way as the natural gas, is fed to the combuster with a somewhat over-stoichiometric flow in relation to the flow of natural gas. The flow of steam produced in the steam generator (3) connected to the gas turbine´s (1) exhaust outlet together with a part flow of the flue gas from said steam generator (3) after directly or indirectly temperature controlled compression in the gas turbine´s compressor(s) (11/12), are simultaneously fed to the combuster (13). In order to avoid too high local combustion temperatures the oxygen is suitably mixed with the gas flow from the high pressure compressor (12), whereby the flows of natural gas and oxygen are controlled in such a way, that the gas leaving the combuster has a temperature adapted to the gas

turbine (1237°).

After expansion in the gas turbine´s high- and low pressure turbine (HPT/LPT) stages (14/15) the exhaust gas from the latter turbine has a pressure somewhat higher than atmospheric pressure and a temperature of 440°C. The gas is conducted through the steam generator (3), where its temperature is reduced to 120°C while generating high-pressure steam with 400°C temperature and 30 bar pressure (alternatively 550°C and 200 bar for a gas turbine of industrial type according to FIG. 2). The feed water to the steam generator (3) is branched off from the hot-water produced in the scrubber (4) and has a temperature of 94°C.

The steam generator (3) features modular construction with finned-tube heat transfer surface and natural or forced circulation, for instance of the same type as usually used in connection with a combined cycle with condensing steam cycle.

The flue gas from the steam generator (3), which consists of water vapour with 10,4% CO_2 and has 120°C temperature, is split into two part flows, one of which (54,3%), after being moistened beyond the saturation limit, is fed to the suction side of the gas turbine´s (1) low pressure compressor (LPC) (11). The compressor(s) (11/12) increase the gas/steam mixture's pressure to 30 bar and the pressurized gas flow is fed to the gas turbine´s combuster (13), possibly mixed with the flow of oxygen (17) necessary for the combustion.

The rest of the flue gas from the steam generator (3) is fed to the hot-water scrubber (4), suitably of the same type as often is used in the cellulose industry for making hot-water from flue gases. In such a scrubber the flue gases flow vertically upwards trough a series of spray nozzle banks and the wash water flows counter-currently downwards. With a flue gas temperature of 120°C and with the composition of the gas from the steam generator (3), the hot-water from the scrubber reaches 94°C temperature and the gas leaving to the atmosphere 40°C when the feed-water temperature from the heat sink (5) is

20°C.

The flow of hot-water from the scrubber (4) is filtered in a control filter (21), whereafter it is split into two part flows, one of which of security reasons is conducted through a deionizing unit (22), and used, partly as feed water to the steam generator (3), partly for moistening the part of the flue gas from the steam generator, which is recirculated to the gas turbine´s LPC (11). The balance of the hot-water flow from the scrubber is exploited for preheating (18) of gas fuel and oxygen and possibly for selective heating purposes (6) whereafter it is fed to the heat sink (5).

Direct recirculation of the heat of vaporization of steam in the exhaust gas from a gas turbine is not possible in a conventional combined cycle, where the gas turbine uses air as oxygen source for the combustion. The possibility of recycling heat of vaporization according to the invention in the way described above through direct recirculation of flue gas from the steam generator (3) is one of the invention´s advantages and brings about a considerably higher (about 8%-units) total efficiency than can be achieved with the embodiment´s gas turbine in a combined cycle with condensing steam turbine

The gas turbines´ (1) compressors (11/12) have the pressure ratios 1:2,5 and 1:12. In order to minimize superheating of the gas/steam mixture during the compression and thus reduce the energy consumption, atomized hot-water from scrubber (4) is added to the gas/steam mixture from the steam generator (3) in such a controlled flow, that the mixture´s moisture percentage becomes 15% beyond the saturation limit, whereafter the moist mixture is fed to the LPC (11), where it is compressed to 2.5 bar and gets the temperature 128°C and a moisture content of 10% beyond the saturation limit. This moist gas/steam mixture from the LPC (11) is further compressed in the gas turbine´s HPC (12) to 30 bar, turns thereby dry and gets the temperature 332°C whereafter the gas/steam mixture, possibly after mixing with all or part of the oxygen flow (17) necessary for the combustion, is fed to the gas turbine´s

combuster (13).

In order to bring about an effective "atomization" of the 94°C hot-water from the scrubber (4) when moistening the recirculated flue gas flow from the steam generator (3) to the LPC (11), the hot-water is according to the invention heated to > 130°C before it is pumped to spray nozzles in the inlet of the LPC (11). The small drops created by a nozzle explode, when they leave the nozzle, in a large number of micro-drops because the vapour pressure in the inner of a drop is higher than the surrounding pressure, near the atmospheric pressure, that prevails in the suction chamber of the LPC (11). This arrangement brings about that the hot-water forms a mist, which follows the part flow of flue gas from the steam generator (3) through the LPC (11) and which mist successively is reduced through vaporization to the point of disappearance in the HPC (12) when the temperature there exceeds 180°C. The most simple way to heat the hot-water is brought about by pumping the water through a separate pipe coil in the steam generator (3).

The heat content of the hot-water with 94°C temperature, which is not used as above, is most economically exploited for selective heating purposes (6) and the like. The water returning from the selective heating (6), the preheating (18) and the rest of not utilized hot-water from the scrubber (4) is cooled in the heat sink (5) to about 20°C or less, preferably a sink in the form of a heat exchanger operating with e.g. sea water, whereafter the water is recirculated to the top of the scrubber (4). Surplus of the circulating water, originating from the hydrogen content of the natural gas, is drawn off (23) in order to keep the inventory of circulating water constant. If supply of sea water or other type of cooling water is lacking, the cooling can be achieved in cooling towers, whereby the loss of water in case of gas fuel with low hydrogen content may, however, be so high, that fresh water has to be added to the circulation cycle.

Fig. 2 shows a variant of the embodiment according to fig. 1,

which is favourable for industrial type of gas turbines with normally an exhaust gas temperature about 600°C, where the high pressure steam from the steam generator (3) is fed to a back pressure turbine (7) generating power down to the pressure of the gas turbine´s (1) combuster (13) through feeding the back pressure steam to said combuster. The back pressure turbine´s (7) shaft can be connected to the LPC shaft, the gas turbine´s LPT shaft or a separate generator. The specific investment cost and the total efficiency for this variant will be roughly the same as for the method according to the embodiment.

Gas turbines of industrial type usually operates at lower pressure and temperature than aero derived gas turbines, for instance 14 bar and 1190°C, but can be made with higher capacity. The exhaust gas temperature is higher, for instance 590°C, which implies that the variant according to fig. 2 is favourable because the back pressure turbine (7) then can operate with sharper steam data, for instance 200 bar and 550°C.

A compressor stage and turbine stage, respectively of a gas turbine is designed so that the speed of the working medium in the individual stages both for the stator and the rotor blades, is near the sonic speed, which can be computed from the formula

$$a = (\kappa * P/r)^{1/2}$$

where a = sonic speed at the conditions in the stage in question, P = local gas pressure, r = local gas density and κ = the isentropic exponent, which is dependent on the medium´s molecular weight according to the relation

$$(\kappa-1)/\kappa = Ro/M*cp$$

where Ro = gas constant, cp = specific heat at constant pressure and M = the medium´s molecular weight. For the open area of the first turbine stage of the embodiment´s gas turbine the following data are valid for the respective medium:

	CO_2/Steam	Air/Flue gas
a m/s	877	757
M kg/mol	20,7	28,3
κ	1,24	1,31
ρ kg/m^3	4,82	6,86
cp kJ/kg.°C	2,11	1,24
r	1,14	1,00

r = relative energy flow (relative capacity) shows that the gas turbine would have 14% higher capacity with carbon dioxide/steam mixture provided that its mechanical strength so allows. When the gas turbine is of aero-derived type this is probably not the case, and thus the capacity will be the same in both cases.

Start of power generation according to the method of the invention can be achieved through feeding, besides fuel gas (16) and oxygen (17), atomized water instead of steam to the gas turbine´s combuster (13), whereby the water flow is controlled in such a way that the combustion gas from the combuster (13) to the gas turbine¨s HPT (14) has adapted temperature. The water to the combuster is successively phased out simultaneously with the gas flow from the steam generator (3) and the compressors (11/12) build up.

The moist carbon dioxide (20), which leaves the scrubber´s (4) top, is preferably utilized for production of (liquid) carbon dioxide with known methods, suitably a method through which the carbon dioxide is freed from inerts such as residual oxygen etc. Carbon dioxide, gaseous as well as liquid, can be transported in pipelines and has extensive use for "flooding" of oil wells. The carbon dioxide is hereby pumped into the well where it partly dissolves in the oil and makes it more fluid. In this way further oil quantities can be reclaimed.

The embodiment according to fig. 1 implies a total efficiency of 55% when combusting natural gas with oxygen in the combination of equipment units according to the embodiment including a separate oxygen unit. The produced flue gas from the hot-

water scrubber is moist carbon dioxide gas, which is useful for production of (liquid) carbon dioxide, while the surplus of hot-water from the scrubber (4) is useful for selective heating purposes. The net efficiency amounts to 50% after deduction of power consumption for production in a separate unit of liquid carbon dioxide (0,2 kWh/kg carbon dioxide). The method according to the invention implies advantageous use of, besides natural gas, all clean gaseous fuels produced by oxygen gasification of carbonaceous fuels, for instance fossil fuels as coal and oil but biomass as well.

Liquid carbon dioxide can be dumped in the depths of the oceans, in extinguished oil and gas wells, aquiferes etc. Dumping in combination with the method according to the invention enables thus power generation based on gaseous fuels without increasing the carbon dioxide content of the atmosphere, which implies that the method enables power supply based on fossil fuels, which is as environment friendly as power generation based on biofuels but more energy efficient.

An important environmental advantage of power generation according to the method of the invention is the total absence of nitrogen oxides in the flue gas, which is put into the atmosphere. Another advantage is the absence of the comprehensive cleaning devices for the air intake, which the conventional combined cycle requires.

Claims

1. A method for power generation based on combustion of gaseous fuels, **characterized by** a thermal power generation cycle with a gas turbine (1) as principal machine, whereby the gas turbine´s working-medium consists of the gaseous mixture of water vapour and carbon dioxide, which is formed by combustion of fuel gas (16) with oxygen (17), of somewhat over-stoichiometric flow in relation to the fuel flow, in the gas turbine´s (1) combuster and during simultaneous supply of a steam flow produced at adapted pressure in a steam generator (3) connected to the gas turbine´s (1) exhaust outlet and during likewise simultaneous recirculation to the combuster (13) of a part flow of the flue gas from said steam generator (3) after compression in the gas turbine´s compressor(s) (11/12) during temperature control through direct or indirect cooling, whereby the fuel gas flow (16) is controlled in such a way that the produced hot gas mixture has a temperature adapted for admission to the gas turbine (1).

2. A method according to claim 1, **characterized in** that the steam generator (3) connected to the exhaust gas outlet of the gas turbine (1) delivers steam at the highest possible pressure and temperature compatible with the turbine´s exhaust gas temperature and that said steam is fed to a back pressure turbine (7) with so adapted back pressure, that the exhaust steam can be fed to the gas turbine´s (1) combuster (13) and whereby the back pressure turbine (7) is connected to the gas turbine´s (1) shaft or a separate generator.

3. A method according to one or both the claims 1-2, **characterized in** that the non-recirculated part flow of flue gas from the steam generator (3) is utilized for production of hot-water through direct contact with cold water in a scrubber (4) of known type, whereby a part flow of the produced hot-water is utilized, partly for said temperature control in the gas turbine´s (1) compressor(s), partly as feed water to the steam generator (3).

4. A method according to claim 3, **characterized in** that the atomization of hot-water, used for temperature control in the gas turbine´s (1) compressor(s) through moistening of the recirculated part flow of flue gas from the steam generator (3), is brought about through heating of hot-water from the scrubber (4) to > 130°C under pressure before the water is fed to spray nozzles of known type in the suction chamber of the gas turbine´s (1) compressor(s).

5. A method according to claim 3, **characterized in** that the part of the hot-water from the scrubber (4), which is not used for temperature control in the gas turbine´s (1) compressor(s) through moistening respectively as feed water to the steam generator (3), is utilized for, partly preheating (18) of fuel gas respectively oxygen to the gas turbine´s combuster (13), partly other purposes as selective heating (6), whereafter the water is recirculated to the scrubber (4) after adapted cooling in a heat sink (5), which can be of type cooling tower or heat exchanger with for instance sea water as cooling medium, whereby the inventory of circulating water is kept constant through tapping (23) the surplus water originating from the fuel gas´ hydrogen content.

6. A method according to claim 3, **characterized in** that the total flow of hot-water from scrubber (4) is filtered in a control filter (21) and that the part flows, which are distributed as feed water to the steam generator (3) respectively for moistening part of the flue gas flow from the steam generator (3), is deionized in an ion-exchanging unit (22).

7. A method according to claim 3, **characterized in** that the moist carbon dioxide leaving the top of the hot-water scrubber (4) is utilized for production of gaseous or liquid carbon dioxide in a known way.

8. A method according to claim 1, **characterized in** that for starting power generation, besides fuel gas (16) and oxygen (17), atomized water is fed to the gas turbine´s (1) combuster (13) in such a controlled flow that the gas tur-

bine´s turbines (14/15) receive combustion gas of adapted temperature and pressure, whereby the water successively is phased out and replaced by compressed flue gas and steam from the steam generator (3) when the flows from same and the gas turbine's (1) compressor(s) (11/12) build up.

9. A plant for power generation based on combustion of gaseous fuels, **characterized by** a gas turbine (1) of type derived from jet motors or of industrial type, with passing or divided shaft (jet type) including compressor(s) (11/12), combuster (13) and turbine(s) (14/15), a unit for production of oxygen (2) through distillation of liquid air in a conventional way and connected to the combuster of the gas turbine, a steam generator (3), connected to the exhaust outlet of the gas turbine´s low pressure turbine, producing steam, possibly superheated, with high pressure adapted to the gas turbine´s combuster (13) or a back pressure turbine (7)(fig. 2), a hot-water scrubber (4), on the gas side connected to said steam generator´s (3) flue gas outlet respectively the atmosphere, producing hot-water from part of the flue gas flow from said steam generator, a control filter (21) for the total hot-water flow from the hot-water scrubber (4) and a deionizing unit for the part flow of the hot-water used as feed water respectively for moistening, a heat sink (5) in form of a heat exchanger or cooling tower, cooling circulating water before its reuse, and an electric generator (8) connected to the axle of the gas turbine´s (1) low pressure turbine or power turbine.

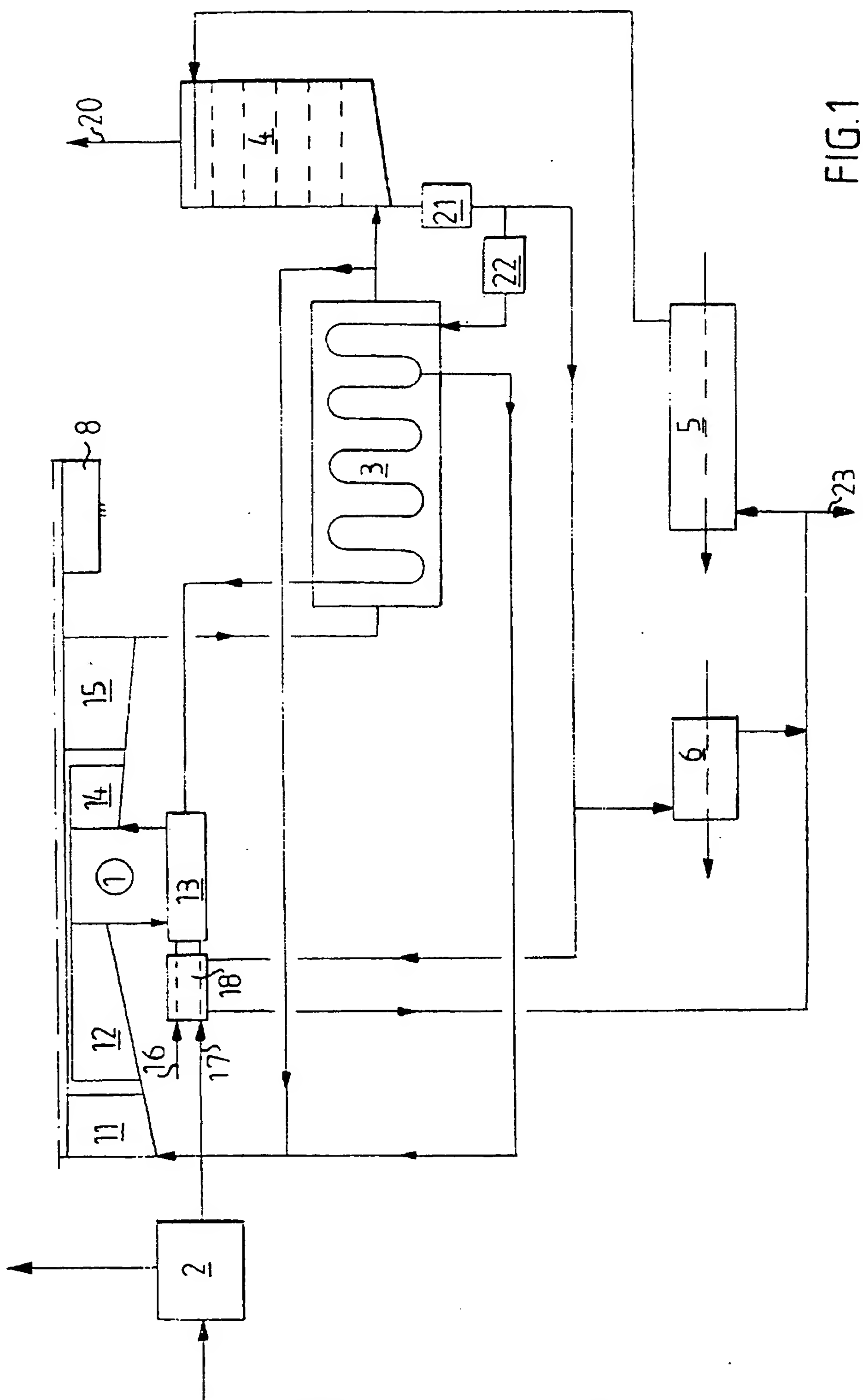

FIG.1

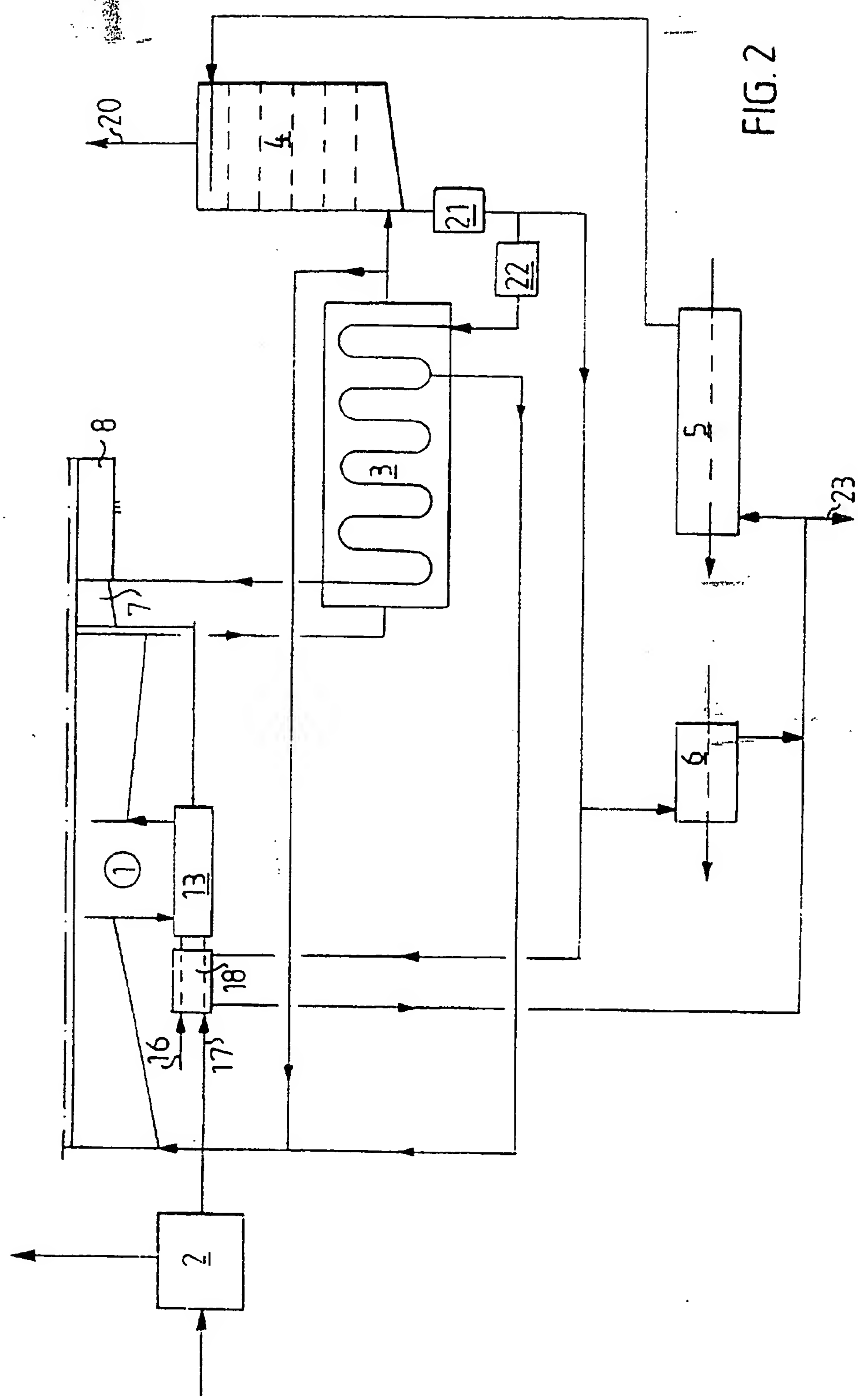

FIG. 2

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

IPC6: F02C 3/30, F02C 3/34

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

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IPC6: F02C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 4204401 A (ERNEST R. EARNEST), 27 May 1980 (27.05.80) --	1-9
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A	EP 0372472 A1 (HITACHI, LTD.), 13 June 1990 (13.06.90) --	1-9

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
8 August 1997	21 -08- 1997
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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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